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A METHOD FOR DETERMINING THE PARAMETERS FOR A PRESCRIBED SHAPE MODIFICATION OF SHEET GLASS

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A method for computing the parameters for a sheet-glass shape modification in production of bent articles is suggested based on the theory of deformation of viscoelastic materials developed by R. Christensen. Use of this method makes it possible to determine theoretically the time and loading parameters of the process.

Under conditions of large-scale production of bend sheet glass, regardless of its structure (triplex or tempered), workpieces of glass articles are necessarily subjected to a shape-modifying (bending) operation by extrusion or molding.

The method proposed earlier for calculating sheet-glass deformation in extrusion [1, 2] included certain simplifications with respect to the regime of heated-piece loading, which was assumed to be instantaneous. It is known that deformation of a workpiece proceeds for a certain time according to a prescribed regime. We have tried to take into account these specific features in a proposed algorithm for computing the parameters of sheet-glass extrusion. Special attention is paid to the deformation stage, when the workpiece is in full or partial contact with the molding surfaces of the matrix or the punch.

The extrusion process occurs in the following way (Fig. 1). In descent with the force $F(\tau)$ the punch *1* acts upon the heated glass sheet *2* and presses it to the matrix *3*, due to which the glass workpiece acquires the shape of the matrix contour. After the workpiece is released, its configuration does not remain constant due to a so called after-effect that is typical of all viscoelastic bodies. Glass at a temperature $t > t_g$ (t_g is the vitrification temperature) belongs to viscoelastic bodies.

Figure 2 shows variations in two extrusion parameters: the displacement of the punch δ and the deflection of the molded glass sheet ω at its center as a function of the extrusion time τ. Approach of the punch and the matrix occurs along the line *OA*, the line *AB* corresponds to holding of the workpiece, and the line *BD* reflects separation of the extruding elements, whereas the numerical values of δ and ω coincide on the segment *BC* due to the elastic after-effect in the workpiece. After the point *C*, the contact of the punch with the workpiece terminates, the workpiece is sent for further technological treatment, and if it is transported horizontally, the parameter ω varies along the curve *CE* as well.

Let us consider each bending stage in sequence.

The loading regime (*OA*) can be represented either by the dependence $F(\tau)$, or by the law of variation of the punch feed with time $\delta(\tau)$. It is more convenient to use the dependence

$$\delta(\tau) = v\tau,$$

where v is the punch movement velocity; τ is the process duration.

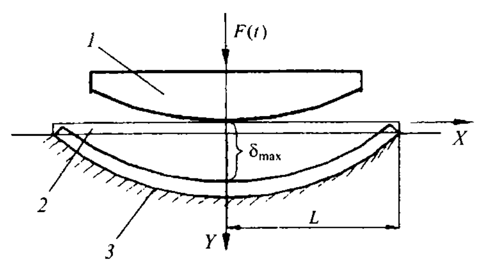

Fig. 1. Sheet-glass extrusion scheme.

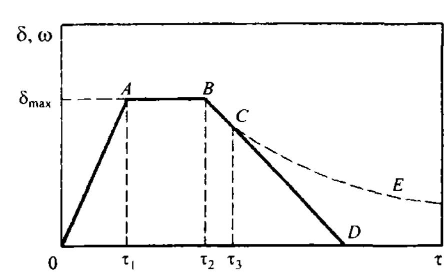

Fig. 2. Extrusion time diagram.

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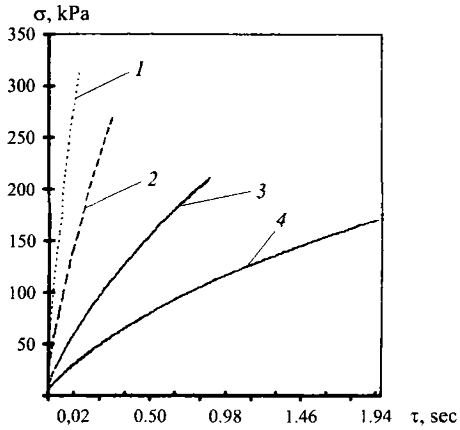

Fig. 3. Stress variation as a function of the extrusion duration for different velocities: *1*) 0.4 m/sec; *2*) 0.2 m/sec; *3*) 0.08 m/sec; *4*) 0.04 m/sec.

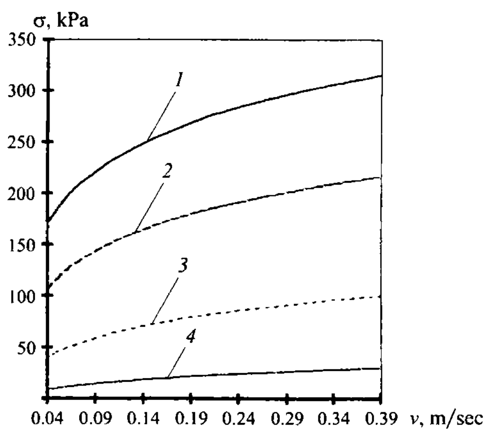

Fig. 4. Stress variation as a function of the extrusion velocity for different temperatures: *1*) 620°C; *2*) 630°C; *3*) 650°C; *4*) 680°C.

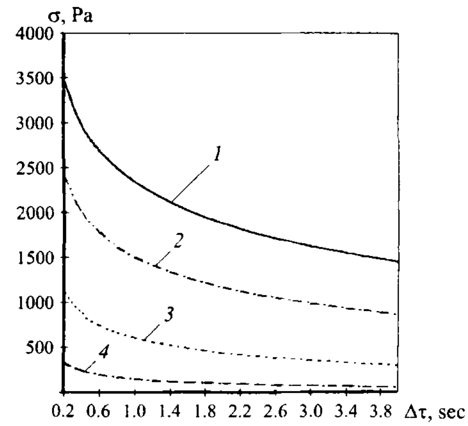

Fig. 5. Dependence of the stress relaxation on the extrusion duration for different temperatures: *1*) 620°C; *2*) 630°C; *3*) 650°C; *4*) 680°C.

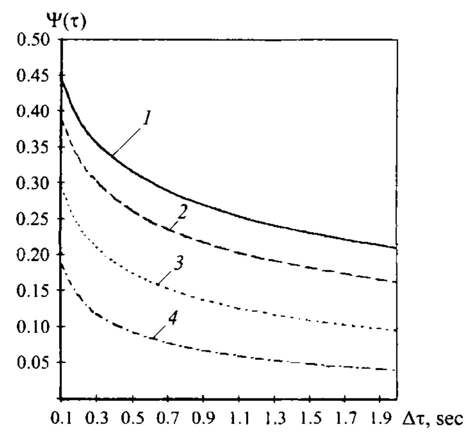

Fig. 6. Variation of the coefficient Ψ as a funnction of the extrusion duration for different temperatures: *1*) 620°C; *2*) 630°C; *3*) 650°C; *4*) 680°C.

Here

$$v = \delta_{\max}/\tau_1, \qquad (1)$$

where $\delta_{\max}$ is the maximum sheet deflection in bending; τ_1 is the deformation time.

Taking into account Eq. (1),

$$\delta(\tau) = \frac{\delta_{\max}}{\tau_1}\tau,$$

where τ varies from 0 to τ_1.

If the punch profile is described by a cubic parabola, the coordinate of each of its points in bending can be found from the relationship

$$y = \delta(\tau) - c\,|x|^3,$$

where c is a coefficient determined by the workpiece geometry; x is the coordinate of the calculation point.

To compute all necessary process parameters, one can use R. Christensen's data [3]. In particular, stress variations in the deformed workpiece will obey the following expression:

$$\sigma(\tau) = R(0)\left[\frac{1}{\gamma(\tau)} - 1\right] - \int_0^{\tau} \frac{dR(\tau-\zeta)}{d\zeta}\left[\frac{1}{\gamma(\tau)}\right] d\zeta, \qquad (2)$$

where

$$\gamma(\tau) = \left[1 - \frac{\delta(\tau)}{cL^3}\right]^{1/2};$$

$R(\tau-\zeta)$ is the relaxation function, and

$$R(\tau) = \frac{\sigma(\tau)E(0)}{\sigma(0)},$$

where σ(0) is the stresses in the initial stage of relaxation; $E(0)$ is the modulus of elongation.

If one imposes the relaxation law of O. V. Mazurin [4]

$$\sigma(\tau) = \sigma(0) \exp [-(\tau/\tau_r)^b],$$

where τ_r is the relaxation time and b is a constant, then

$$R(\tau) = E(0) \exp [-(\tau/\tau_r)^b].$$

At $\tau = 0$, the value of the expression whose exponent is taken will be equal to zero, and consequently, the exponent itself will be equal to unity. In this case one can write $E(0) = R(0)$. Then Eq. (2) will take the form

$$\sigma(\tau) = E(0)\left[\frac{1}{\gamma(\tau)} - 1\right] - \int_0^\tau E(0)\frac{b\tau^{b-1}}{\tau_r^b}\left[1 - \frac{1}{\gamma(\tau)}\right] \exp\left[-\left(\frac{\tau}{\tau_r}\right)^b\right] d\tau. \quad (3)$$

That is, if we substitute $\tau = \tau_1$ into Eq. (3), the level of stresses at the end of the phase of approach of the molding elements, denoted by $\sigma(\tau) = \sigma(\tau_1)$, will be known.

Holding the workpiece along the line AB (Fig. 2) has the purpose of maximum relaxation of stresses caused by deformation prior to the moment $\tau = \tau_2$. Since the holding duration is $\Delta\tau = \tau_2 - \tau_1$, the stresses will be equal to

$$\sigma(\tau_2) = \sigma(\tau_1) \exp [-(\Delta\tau/\tau_r)^b]. \quad (4)$$

Denoting $\dfrac{\sigma(\tau_2)}{\sigma(\tau_1)} = \Psi$ and solving Eq. (4) with respect to $\Delta\tau$, we obtain

$$\Delta\tau = \tau_r(-\ln\Psi)^{1/b},$$

which makes it possible to obtain subsequently a series of curves describing the main technological parameters of sheet-glass extrusion, such as the stress variation as a function of the extrusion duration for different speeds of punch movement, the dependence of the stress variation on the extrusion rate and the process duration for different temperatures, and the dependence of the coefficient Ψ on the extrusion duration (Figs. 3 – 6).

Based on the constructed graphs, one can find the most rational technological parameters for sheet-glass extrusion.

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